# RHEOFORMING APPARATUS

## BACKGROUND OF THE INVENTION

This application claims the priority of Korean Patent Application No. 2004-7227, filed on February 4, 2004, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

1. Field of the Invention

The present invention relates to a rheoforming apparatus, and more particularly, to a rheoforming apparatus for manufacturing predetermined products from semi-solid metal slurries with a fine, uniform, spherical particle structure.

2. Description of the Related Art

Metal slurries in a combined solid and liquid phase, i.e., semi-molten or semi-solid metal slurries, generally refer to intermediates manufactured by composite processing of rheoforming and thixoforming. Semi-solid metal slurries consist of solid particles suspended in a liquid phase in an appropriate ratio at temperature ranges of a semi-solid state, and thus, they can be transformed even by a little force due to their thixotropic properties and can be easily cast like a liquid due to their high fluidity.

Rheoforming refers to a process of manufacturing billets or final products from semi-solid metal slurries having a predetermined viscosity through forming or forging. Such rheoforming is closely related to thixoforming and thus is also expressed as rheoforming/thixoforming. Thixoforming refers to a process involving reheating billets manufactured through rheoforming back into semi-molten slurries and forming or forging the slurries to manufacture final products.

Such rheoforming/thixoforming has many advantages, compared to general forming processes using molten metals, such as casting or squeeze-forming. Because metal slurries used in rheoforming/thixoforming are fluid at a temperature lower than molten metals, it is possible to maintain dies contacting with the slurries at a lower temperature than the molten metals, thereby extending the lifespan of the dies.

In addition, when slurries are extruded through a cylinder, turbulence is less likely to occur, and thus less air is incorporated during forming. Therefore, the formation of air pockets in final products is prevented. Besides, the use of semi-solid metal slurries leads to reduced shrinkage during solidification, improved working efficiency, mechanical properties, and anti-corrosion property, and lightweight products. Therefore, such semi-solid metal slurries can be used as new materials in the fields of automobiles, airplanes, and electrical, electronic information communications equipment.

As described above, semi-solid metal slurries are used both in rheoforming and thixoforming. In detail, semi-solid slurries solidified from molten metals by a predetermined method are used in rheoforming, and semi-molten slurries obtained by reheating solid billets are used in thixoforming. Throughout the specification of the present invention, the term "semi-solid metal slurries" means metal materials in a combined solid and liquid state at a temperature range between the liquidus temperature and the solidus temperature of metals, i.e., at a semi-solid temperature range at which the crystalline particles of metals are partially molten and are partially solid, or semi-solid slurries which are obtained by cooling molten metals during rheoforming.

Meanwhile, conventional rheoforming is largely classified into a nuclei formation method using crystalline nuclei grown in molten metals and a stirring method of destroying dendrites grown in molten metals, according to a slurry manufacturing method.

In a conventional nuclei formation method, nuclei formation and growth are slowly performed since the pouring temperature of molten metals is maintained at a very low level and a cooling rate is very slow. Therefore, the process duration is excessively retarded, which renders mass production difficult.

In a conventional stirring method, molten metals are generally stirred at a temperature lower than the liquidus temperature during cooling, to destroy dendrites into spherical particles suitable for rheoforming, for example, by mechanical stirring, electromagnetic stirring, gas bubbling, low-frequency, high-frequency, or electromagnetic wave vibration, electrical shock agitation, etc.

For example, U.S. Patent No. 3,948,650 discloses a method and an apparatus for manufacturing a liquid-solid mixture. In this method, a molten metal is vigorously stirred while being cooled for solidification. A semi-solid metal slurry

manufacturing apparatus disclosed in this patent uses a stirrer to induce flow of the solid-liquid mixture having a predetermined viscosity to destroy dendritic structures or disperse destroyed dendritic structures in the liquid-solid mixture. In this method, dendritic structures formed during cooling are destroyed and used as crystalline nuclei for spherical particles. However, because of generation of latent heat due to formation of solidification layers at an early stage of cooling, the method causes problems of low cooling rate, long process duration, uneven temperature distribution in a mixing vessel, and non-uniform crystalline structure. Mechanical stirring applied in the semi-solid metal slurry manufacturing apparatus inherently leads to uneven temperature distribution in the mixing vessel. In addition, because the mixing vessel is located at a chamber, it is difficult to continuously perform a subsequent process.

U.S. Patent No. 4,465,118 discloses a method and an apparatus for manufacturing a semi-solid alloy slurry. A cooling manifold and a die are sequentially arranged in a coiled electromagnetic field application unit. A molten metal at an upper position of the die is continuously poured into the die, and cooling water flows through the cooling manifold to cool the die. According to the method disclosed in this patent, a molten metal is poured into the die and cooled in the cooling manifold, thereby resulting in a solidification zone. When a magnetic field is applied by the electromagnetic field application unit, dendritic structures are destroyed during cooling. Finally, an ingot is formed and then drawn through a lower portion of the apparatus. However, since the basic technical idea of this method and apparatus is to destroy dendrites by vibration after solidification, the above-described many problems in terms of a manufacturing process and a slurry structure are involved. In the manufacturing apparatus, since a molten metal is continuously supplied to form an ingot, it is difficult to control the state of the molten metal and the overall process. Moreover, prior to applying an electromagnetic field, the die is cooled using water, whereby a great temperature difference exists between the peripheral and core regions of the die.

Other types of rheoforming/thixoforming known in the art are described later. However, all of the methods are based on the technical idea of destroying dendrites after their formation to form crystalline nuclei of spherical particles. Therefore, problems as described above arise.

Japanese Patent Application Laid-open Publication No. Hei. 11-33692 discloses a method of manufacturing a metal slurry for rheoforming. According to the method disclosed, a molten metal is poured into a vessel at a temperature near its liquidus temperature or 50℃ above the liquidus temperature. Next, when at least a portion of the molten metal reaches a temperature lower than the liquidus temperature, i.e., at least a portion of the molten metal starts to pass through the liquidus temperature, the molten metal is subjected to a force, for example, ultrasonic vibration, and slowly cooled into the metal slurry containing spherical particles. This method also uses a physical force, such as ultrasonic vibration, to destroy the dendrites formed at an early stage of cooling. Also, if the pouring temperature is higher than the liquidus temperature, it is difficult to form spherical particle structures and to rapidly cool the molten metal. Furthermore, this method leads to non-uniform surface and core structures.

Japanese Patent Application Laid-open Publication No. Hei. 10-128516 discloses a method for casting a thixotropic metal. This method involves pouring a molten metal into a vessel and vibrating the molten metal using a vibrating bar dipped in the molten metal to directly transfer a vibrating force to the molten metal. After forming a semi-solid and semi-liquid molten alloy which contains crystalline nuclei at a temperature range lower than the liquidus temperature, the molten alloy is cooled to a temperature at which it has a predetermined liquid fraction, and then left stand from 30 seconds to 60 minutes to allow for the growth of the nuclei, thereby resulting in the thixotropic metal. However, this method provides relatively large crystalline nuclei of about 100 ㎛, requires a considerably long process duration, and cannot be performed in a vessel larger than a predetermined size.

U.S. Patent No. 6,432,160 discloses a method for making a thixotropic metal slurry. This method involves simultaneously controlling the cooling and the stirring of a molten metal to form the thixotropic metal slurry. In detail, after pouring a molten metal into a mixing vessel, a stator assembly positioned around the mixing vessel is operated to generate a magnetomotive force sufficient to rapidly stir the molten metal in the vessel. Next, the molten metal is rapidly cooled by means of a thermal jacket, equipped around the mixing vessel, for precise temperature control of the mixing vessel and the molten metal. During cooling, the molten metal is continuously stirred in such a manner that when the solid fraction of the molten metal

is low, high-speed stirring is provided, and when the solid fraction of the molten metal increases, a greater magnetomotive force is applied.

Most of the aforementioned conventional rheoforming/thixoforming methods and apparatuses use a shear force to destroy dendrites into metal particle structures during cooling. Since a force such as vibration is applied after at least a portion of the molten metal is cooled below its liquidus temperature, latent heat is generated due to formation of solidification layers at an early stage of the cooling. As a result, there arise many disadvantages such as reduced cooling rate and increased process duration. In addition, due to uneven temperature distribution between the inner wall and the center of a vessel, it is difficult to form fine, uniform spherical metal particles. Therefore, this structural non-uniformity of metal particles will worsen if the pouring temperature of the molten metal into the vessel is not controlled.

Meanwhile, in the above-described rheoforming apparatuses, billets are manufactured by a continuous forming method, which makes it difficult to directly manufacture products from prepared slurries by a forming process.

## SUMMARY OF THE INVENTION

The present invention provides a rheoforming apparatus that ensures the manufacturing of products with fine, uniform, spherical particles, with improvements in energy efficiency and mechanical properties, manufacturing cost reduction, convenience of forming, and shorter process duration.

The present invention also provides a rheoforming apparatus for manufacturing products within a short time, with improvement in durability reduction of constitutional elements of the apparatus due to pressing and an energy loss.

In accordance with an aspect of the present invention, there is provided a rheoforming apparatus comprising: a first sleeve, an end of which is formed with a slurry outlet port for releasing a slurry; a second sleeve for retaining a molten metal, an end of which communicates with the first sleeve; a sealing member for opening or closing the end of the second sleeve; a stirring unit for applying an electromagnetic field to the second sleeve; and a first plunger, which is slidably inserted into the other end of the second sleeve to press the slurry manufactured in the second sleeve.

The sealing member may be a stopper that is removably installed at the end of the second sleeve communicating with the first sleeve.

The rheoforming apparatus may further comprise a forming unit, which is installed outside the slurry outlet port of the first sleeve to form a predetermined product from the slurry released from the slurry outlet port.

In this case, the forming unit may comprise: a transfer roller for transferring the slurry released from the slurry outlet port; and a cooler for cooling the slurry transferred by the transfer roller.

The forming unit may be a press-forming unit comprising a press die that forms a predetermined product by pressing the slurry released from the slurry outlet port.

The forming unit may be a forming die comprising a moving die and a fixing die that define a predetermined forming cavity so that the slurry released from the slurry outlet port is inserted into the forming cavity.

The rheoforming apparatus may further comprise a first temperature control unit, which is installed around the first sleeve to adjust the temperature of the slurry pressed toward the slurry outlet port.

The rheoforming apparatus may further comprise a second temperature control unit, which is installed around the second sleeve to adjust the temperature of the molten metal retained in the second sleeve.

The second sleeve may be made of a non-magnetic material.

The first sleeve may have a cylindrical shape parallel to the ground, and the second sleeve may be coupled with the first sleeve by moving at a predetermined angle with respect to the first sleeve.

The stirring unit may move together with the second sleeve.

The second sleeve may be branched from the first sleeve, and the rheoforming apparatus may further comprise a second plunger slidably inserted into the other end of the first sleeve to press the slurry in the first sleeve toward the slurry outlet port.

The second sleeve may be formed in a shape flared from the end intended for the insertion of the first plunger to the end communicating with the first sleeve.

The rheoforming apparatus may further comprise an electromagnetic field control unit, which is electrically connected to the stirring unit and controls the stirring unit in such a manner that an electromagnetic field is applied to the second sleeve from prior to pouring the molten metal in the second sleeve and is stopped when crystalline nuclei are formed in the molten metal.

## BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. 1 schematically illustrates a structure of a rheoforming apparatus according to a first embodiment of the present invention;

FIG. 2 is a sectional view of an example of a second sleeve used in the rheoforming apparatus of FIG. 1;

FIGS. 3 through 6 illustrate a sequential process for manufacturing an extrudate using the rheoforming apparatus according to the first embodiment of the present invention;

FIG. 7 is a graph of a temperature profile applied to a rheoforming apparatus according to the present invention;

FIG. 8 schematically illustrates a structure of a rheoforming apparatus according to a second embodiment of the present invention;

FIGS. 9 through 14 schematically illustrate operational states of a rheoforming apparatus according to a third embodiment of the present invention;

FIGS. 15 through 17 schematically illustrate operational states of a rheoforming apparatus according to a fourth embodiment of the present invention;

FIGS. 18 and 19 schematically illustrate operational states of a rheoforming apparatus according to a fifth embodiment of the present invention;

FIGS. 20 and 21 schematically illustrate operational states of a rheoforming apparatus according to a sixth embodiment of the present invention;

FIG. 22 schematically illustrates a structure of a rheoforming apparatus according to a seventh embodiment of the present invention;

FIG. 23 schematically illustrates a structure of a rheoforming apparatus according to an eighth embodiment of the present invention; and

FIG. 24 schematically illustrates a structure of a rheoforming apparatus according to a ninth embodiment of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

The present invention will be described more fully in the following exemplary embodiments of the invention with reference to the accompanying drawings.

A rheoforming apparatus according to the present invention is used to manufacture products with a predetermined shape using semi-solid slurries.

A first embodiment of the present invention will first be described with reference to FIGS. 1 through 7.

In a rheoforming process performed using the apparatus of the first embodiment of the present invention shown in FIGS. 1 through 7, a molten metal M is poured into a second sleeve 22 to form a semi-solid metal slurry S and then the slurry is extruded at a low pressure. In this case, the molten metal M is stirred by applying an electromagnetic field before the molten metal is completely poured into the second sleeve 22. That is, electromagnetic stirring is performed before the molten metal is completely poured into the second sleeve 22 to prevent the formation of solidification layers and dendrites at an early stage. The stirring process may be performed using ultrasonic waves instead of the electromagnetic field.

In detail, after application of an electromagnetic field to a predetermined portion of the second sleeve 22 surrounded by a stirring unit 1 is begun, the molten metal is poured into the second sleeve. At this time, the electromagnetic field has a sufficient intensity so that solidification layers or dendrites are not formed in the molten metal at an early stage.

As shown in FIG. 7, the molten metal is poured into the second sleeve 22 at a pouring temperature Tp. As described above, an electromagnetic field may be applied to the second sleeve 22 prior to pouring the molten metal into the second sleeve 22. However, the present invention is not limited to this, and electromagnetic stirring may be performed simultaneously with or in the middle of pouring the molten metal into the second sleeve.

Due to the electromagnetic stirring performed before the molten metal is completely poured into the second sleeve 22, solidification layers are not formed in the molten metal near the inner wall of the cold second sleeve 22 at an early stage, which renders formation of dendrites difficult. That is, because the molten metal is poured into the second sleeve 22 during applying an electromagnetic field to the second sleeve 22, temperature differences between the inner wall and the center of the second sleeve 22 and between the upper portion and the lower portion of the second sleeve 22 are hardly caused. Therefore, unlike conventional techniques, solidification near the inner wall of a vessel at an early stage does not occur. Also,

numerous micronuclei are concurrently generated because the entire molten metal in the second sleeve 22 is uniformly and rapidly cooled to a temperature lower than its liquidus temperature.

By applying an electromagnetic field prior to or simultaneously with pouring the molten metal into the second sleeve 22, the molten metal is actively stirred in the center and inner wall regions of the second sleeve 22 and heat is rapidly transferred throughout the second sleeve 22. Therefore, at an early stage of cooling, the formation of solidification layers near the inner wall of the second sleeve 22 is prevented.

In addition, such active stirring of the molten metal induces a convection heat transfer between the hot molten metal and the inner wall of the cold second sleeve 22, thereby rapidly cooling the molten metal. Due to the electromagnetic stirring, particles contained in the molten metal scatter simultaneously with pouring the molten metal into the second sleeve 22 and are uniformly dispersed in the form of crystalline nuclei throughout the second sleeve 22. Therefore, a temperature difference throughout the second sleeve 22 is not caused during cooling. However, in conventional techniques, when the molten metal contacts with a low temperature inner vessel wall, solidification layers are formed at the inner wall of the vessel and then grow into dendrites.

The principles of the present invention will become more apparent when described in connection with solidification latent heat. That is, the molten metal is not solidified at the inner wall of the second sleeve 22 at an early stage of cooling, and thus, no solidification latent heat is generated. Accordingly, discharge of the amount of heat corresponding to only the specific heat of the molten metal, which corresponds to about 1/400 of the solidification latent heat, is required to cool the molten metal.

Therefore, solidification layers and dendrites which are frequently generated at the inner wall of a sleeve at an early stage of cooling like in conventional methods are not formed. The entire molten metal in the second sleeve 22 can be uniformly and rapidly cooled within merely about 1 to 10 seconds from the pouring of the molten metal. As a result, numerous crystalline nuclei are uniformly dispersed throughout the molten metal in the second sleeve 22. The increased nuclei density reduces the distance between the nuclei, which enables formation of spherical particles, instead of dendrites.

The same effects can be achieved even when an electromagnetic field is applied in the middle of pouring the molten metal into the second sleeve 22. In other words, application of an electromagnetic field before the pouring of the molten metal into the second sleeve 22 is completed renders formation of solidification layers at the inner wall of the second sleeve 22 difficult.

It is preferable to limit the pouring temperature, Tp, of the molten metal to a range from its liquidus temperature to 100℃ above the liquidus temperature (melt superheat = 0 to 100℃). Since the entire molten metal contained in the second sleeve 22 is uniformly cooled, as described above, there is no need to cool the molten metal to near its liquidus temperature prior to pouring the molten metal into the second sleeve 22 and the molten metal may have a high temperature of 100℃ above the liquidus temperature.

On the other hand, in a conventional method, after the pouring of a molten metal into a vessel is completed, an electromagnetic field is applied to the vessel when a portion of the molten metal reaches a temperature below its liquidus temperature. Accordingly, at an early stage of cooling, latent heat is generated due to the formation of solidification layers near the inner wall of the vessel. Because the solidification latent heat is about 400 times greater than the specific heat of the molten metal, a significant time is required to drop the temperature of the entire molten metal below the liquidus temperature. Therefore, in such a conventional method, to shorten a process duration, the molten metal is generally poured into a vessel after being cooled to a temperature near the liquidus temperature or a temperature of 50℃ above the liquidus temperature.

According to the present invention, the electromagnetic stirring may be stopped at any point after at least a portion of the molten metal in the second sleeve 22 reaches a temperature lower than the liquidus temperature $T_l$, i.e., after crystalline nuclei of a predetermined amount is formed so that a solid fraction is about 0.001, as shown in FIG. 7. That is, the electromagnetic stirring may be stopped when the molten metal in the second sleeve 22 reaches a temperature near its liquidus temperature or when crystalline nuclei are uniformly formed in the molten metal in the second sleeve 22.

With respect to nuclei density in manufacturing the semi-solid metal slurry from the molten metal, the nucleation in the molten metal is stopped when the solid fraction of the molten metal exceeds 0.0001 ($10^{-4}$) irrespective of the type of a metal

or alloy material for the molten metal. Meanwhile, it is difficult to measure the solid fraction of the molten metal to a level of 0.0001. Therefore, to manufacture a semi-solid metal slurry commercially available, there is no need to carry out the nucleation of the molten metal until the solid fraction of the molten metal is 0.0001. The solid fraction of 0.001 or more is sufficient. Even with respect to productivity, the solid fraction of 0.001 or more is preferred.

Meanwhile, nuclei density in the molten metal can be sufficiently increased by applying an electromagnetic field only during formation of crystalline nuclei in the molten metal. Even though the electromagnetic field is applied to the molten metal for a longer time, the semi-solid metal slurry can be manufactured. However, applying the electromagnetic field even when the solid fraction of the molten metal exceeds 0.1 is not preferable in view of energy efficiency. Also, the structure of the semi-solid metal slurry may become coarse and a process duration may become long.

The electromagnetic field can be continuously applied to the molten metal M in the second sleeve 22 until the cooling process of the molten metal, just before performing a subsequent pressing process, for example, a forming process. This is because once crystalline nuclei are uniformly distributed throughout a slurry manufacturing area of the second sleeve 22, the electromagnetic stirring at the time of growth of crystalline particles from the nuclei does not affect properties of the semi-solid metal slurry.

Therefore, the electromagnetic stirring may be carried out at least until the solid fraction of the metal in the second sleeve 22 is 0.001 to 0.7. That is, the electromagnetic stirring may be stopped when the solid fraction of the metal is 0.001 to 0.7. However, in view of energy efficiency, it is preferable to carry out the electromagnetic stirring until the solid fraction of the metal in the second sleeve is in a range of 0.001 to 0.4, and more preferably 0.001 to 0.1.

When uniform crystalline nuclei are formed by the electromagnetic stirring carried out before the molten metal is completely poured into the second sleeve 22, the second sleeve 22 is cooled to promote the growth of the nuclei. In this regard, the cooling process may be performed simultaneously with the pouring of the molten metal into the second sleeve 22. Also, the electromagnetic field may be continuously applied during the cooling process. That is, the cooling process may be carried out during the application of the electromagnetic field to the second sleeve

22. Therefore, the semi-solid metal slurry manufactured in the second sleeve 22 can be directly used in a subsequent process, i.e., a forming process. Such a cooling process may be carried out by a separate second temperature control unit 44 or may be spontaneously carried out by air.

Such a cooling process may be carried out until just prior to a subsequent process such as pressing and forming, and preferably, until the solid fraction of the metal is 0.1 to 0.7, i.e., up to time $t_2$ of FIG. 7. In detail, when a product made from the semi-solid metal slurry S has a thin thickness and a complicated shape, the cooling is carried out until the solid fraction of the molten metal is 0.1 (by experiment) so that the molten metal is approximately in a liquid phase. Also, there is need to increase a time required for solidification of the semi-solid metal slurry S in a die so that an insertion rate of the slurry into the die is promoted. On the other hand, when a product made from the semi-solid metal slurry S has a thick thickness and a simple shape, the cooling is carried out until the solid fraction of the metal is 0.7 so that the molten metal is approximately in a solid phase. Also, there is need to decrease a time required for solidification of the slurry S in a die so that an insertion rate of the slurry into the die is retarded.

When the solid fraction of the metal used in manufacturing the slurry is 0.1 to 0.7, irrespective of the type of a metal or alloy material for the metal, it is possible to manufacture products of any shape from the slurry made from the molten metal. The manufacture of the slurry with the solid fraction of 0.1 to 0.7 merely occurs within 30 to 60 seconds from the pouring of the molten metal into the second sleeve 22. Therefore, in order to manufacture the slurry from the molten metal within 60 seconds, it is preferable to perform the cooling process until the solid fraction of the metal is 0.1 to 0.7.

The molten metal may be cooled at a rate of 0.2 to 5.0℃/sec. The cooling rate may be any value between 0.2 and 2.0℃/sec depending on a desired distribution of crystalline nuclei and a desired size of particles.

If the cooling rate of the molten metal is less than 0.2℃/sec, crystalline nuclei may excessively grow in the molten metal, thereby increasing a time required for slurry manufacturing. Therefore, productivity and mechanical properties may be lowered. In this regard, it is necessary to set the cooling rate of the molten metal to 0.2℃/sec or more. Generally, it is preferable to increase the cooling rate of the molten metal because a time required for slurry manufacturing is shortened and

energy efficiency is enhanced. However, if the cooling rate of the molten metal exceeds 0.5℃/sec, dendrites may be formed in the molten metal and solidified during cooling.

Meanwhile, when distances between crystalline nuclei formed in the molten metal are large, the nuclei can grow into a large size in the molten metal by cooling the molten metal at a relatively slow rate of 0.2℃/sec. On the other hand, when distances between the nuclei formed in the molten metal are small, it is preferable to perform the cooling at a relatively fast rate of 0.5℃/sec because there is no need to largely increase the size of the nuclei in the molten metal.

When the section area of the second sleeve 2 containing the molten metal is large, it is preferable to perform the cooling at a relatively slow rate of 0.2℃/sec. On the other hand, when the section area of the second sleeve 2 containing the molten metal is small, even relatively fast cooling rate of 0.5℃/sec enables sufficient growth of crystalline nuclei in the molten metal.

Here, formation of crystalline nuclei in the molten metal poured in the second sleeve 22 depends on the temperature of the molten metal when the molten metal is poured in the second sleeve 22, i.e., the pouring temperature. The pouring temperature can be represented by the degree of heating of the molten metal from the liquidus temperature, like a temperature of 100℃ above the liquidus temperature. The degree of heating significantly affects steps ranging from pouring the molten metal in the second sleeve 22 to nucleation.

On the other hand, crystal growth carried out until solidification of the semi-solid metal slurry in a die after nucleation in the molten metal is affected by the thickness of a product made from the molten metal. Therefore, the rate of the cooling for nuclei growth after completion of nucleation by electromagnetic field application depends on the degree of heating of the molten metal for nucleation prior to pouring the molten metal in the second sleeve 22 and the thickness of a product made from the slurry. That is, when the degree of heating of the molten metal is constant and the thickness of a product is given, the cooling rate of the slurry to be inserted in a die is spontaneously determined.

When the degree of heating of the molten metal is high, the number of crystalline nuclei formed in the molten metal decreases. In this regard, it is necessary to retard the cooling rate of the molten metal poured in the second sleeve. On the other hand, when the degree of heating of the molten metal is low, the

number of crystalline nuclei formed in the molten metal increases. In this regard, it is necessary to promote the cooling rate of the molten metal, thereby decreasing the particle size of the slurry.

Therefore, when the cooling rate of the molten metal is 0.2 to 5.0℃/sec and the molten metal at the time of being poured in the second sleeve has a temperature ranging from its liquidus temperature to 100℃ above the liquidus temperature, the semi-solid metal slurry that can be used in the casting industry or has a predetermined solid fraction can be manufactured. The manufactured semi-solid metal slurry can be directly subjected to press-forming, to form a predetermined product.

According to the aforementioned process, the semi-solid metal slurry can be manufactured within a short time. That is, a time ($t_2$) required for manufacturing the slurry with the solid fraction of 0.1 to 0.7 after the pouring of the molten metal into the second sleeve 22 is only 30 to 60 seconds. The slurry thus manufactured can be used in forming a product having a uniform, dense, spherical, crystalline structure.

A rheoforming apparatus using the aforementioned semi-solid slurry manufacture process will now be described with reference to FIGS. 1 through 6.

A rheoforming apparatus as shown in FIGS. 1 through 6 is a vertical type and includes the stirring unit 1 for applying an electromagnetic field and an elongated cylindrical sleeve. The sleeve is divided into the first sleeve 21 for injection and the second sleeve 22 for electromagnetic stirring.

The second sleeve 22 is in a long, slender cylindrical form with both ends open. Since the second sleeve 22 has a vertical axis direction, it is installed to be moved from the vertical axis direction to a horizontal axis direction. With respect to the vertical axis direction of the second sleeve 22, an upper end of the second sleeve 22 is formed with an injection port 25 and a lower end of the second sleeve 22 opposite to the injection port 25 is formed with a slurry outlet port 26. The second sleeve 22 retains the molten metal M coming from the injection port 25.

The second sleeve 22 is formed so that the semi-solid metal slurry made from the molten metal in the second sleeve 22 is released from the slurry outlet port 26. Also, the second sleeve 22 may be formed in a shape gradually flared from the injection port 25 to the slurry outlet port 26. That is, the inner diameter of the second sleeve 22 may be gradually increased toward the releasing direction of the semi-solid metal slurry.

The stirring unit 1 for applying an electromagnetic field to the molten metal contained in the second sleeve 22 is installed around the second sleeve 22. The stirring unit 1 is fixed to the second sleeve 22 to be moved together with the second sleeve 22.

A flat stopper 31 as a sealing member 3 is installed at the slurry outlet port 26 of the second sleeve 22. The stopper 31 is connected to a driving device (not shown) and may be made of the same material as that for the second sleeve 22. As shown in FIG. 1, the stopper 31 seals the slurry outlet port 26 of the second sleeve 22 in a state wherein the injection port 25 of the second sleeve 22 faces upward. In this state, the stopper 31 forms a bottom portion 4 of a slurry manufacturing area T of the second sleeve 22 in which the molten metal is present, thereby allowing the second sleeve 22 to act as a vessel that retains the molten metal.

When the stopper 31 is removed in a state wherein the second sleeve 22 is horizontally positioned, the slurry outlet port 26 of the second sleeve 22 is opened to release the semi-solid metal slurry formed in the second sleeve 22 from the slurry outlet port 26. The stopper 31 may have a door shape, an end of which is hinge-connected to an edge of the slurry outlet port 26 of the second sleeve 22 to be moved. Alternatively, when the stopper 31 is comprised of two parts, the two parts may be separated from each other to render the slurry outlet port 26 open. There are no limitations on the shape of the stopper 31 provided that the slurry outlet port 26 of the second sleeve 22 is allowed to be open or closed.

The second temperature control unit 44 may be further installed around the second sleeve 22, as shown in FIG. 2. The second temperature control unit 44 cools the molten metal contained in the second sleeve 22 or the semi-solid metal slurry manufactured in the second sleeve 22. The second temperature control unit 44 includes a water jacket 46 containing a cooling water pipe 45.

The water jacket 46 is concentrically installed around the second sleeve 22 to surround the outside of the second sleeve 22. The cooling water pipe 45 may be buried in the second sleeve 22. Any coolers capable of cooling the molten metal contained in the second sleeve 22 may be used.

The second temperature control unit 44 includes an electric heating coil 47 as a heater. The electric heating coil 47 may be spirally installed to surround the

outside of the water jacket 46. Any heaters except the electric heating coil 47 may be used.

There are no particular limitations on the structure of the second temperature control unit 44, provided that the second temperature control unit 44 can adjust the temperature of the molten metal or the semi-solid metal slurry in the second sleeve 22. The molten metal contained in the second sleeve 22 is cooled at an appropriate rate using the second temperature control unit 44. The second temperature control unit 44 may be installed around the entire second sleeve 22 or around the slurry manufacturing area T in which the molten metal is present. The molten metal contained in the second sleeve 22 may be spontaneously cooled without the aid of the second temperature control unit 44 to manufacture the semi-solid metal slurry with a desired solid fraction.

In detail, the second temperature control unit 44 may cool the molten metal contained in the second sleeve 22 until the solid fraction of the molten metal is 0.1 to 0.7. The cooling may be carried out at a rate of 0.2 to 5.0℃/sec, preferably 0.2 to 2.0℃/sec.

The cooling by the second temperature control unit 44 may be carried out after the electromagnetic stirring by the stirring unit 1 is completed or irrespective of the electromagnetic stirring, i.e., during the electromagnetic stirring. In addition, the cooling may be carried out simultaneously with the pouring of the molten metal.

Meanwhile, an electromagnetic field application coil 11 is disposed in the stirring unit 1 so as to surround a space 12 defined by the stirring unit 1. The space 12 and the electromagnetic field application coil 11 may be fixed by means of a separate frame (not shown). The electromagnetic field application coil 11 is used to apply an electromagnetic field of a predetermined intensity to the second sleeve 22, which is accommodated in the space 12. Therefore, the molten metal contained in the second sleeve 22 is electromagnetically stirred. There are no particular limitations on the electromagnetic field application coil 11, provided that the electromagnetic field application coil 11 can be used in a conventional electromagnetic stirring process. An ultrasonic stirrer may also be used.

The electromagnetic field application coil 11 may be installed around the second sleeve 22 to be contacted to the outside of the second sleeve 22. By using the electromagnetic field application coil 11, the molten metal can be thoroughly stirred while being poured into the second sleeve 22. When the second sleeve 22

moves, the stirring unit 1 may move together with the second sleeve 22, as shown in FIG. 3. Although not shown in the drawings, it is understood that only the second sleeve 22 can move in a state wherein the electromagnetic field application coil 11 is fixed.

The electromagnetic field application coil 11 is electrically connected to an electromagnetic field control unit 13 for controlling the electromagnetic field application by the stirring unit 1, as shown in FIGS. 1 and 3 through 6. The electromagnetic field control unit 13 may include a control element. The control element includes a switch (not shown) for determining the application of electric powder or electromagnetic field controller (not shown) for controlling an electromagnetic field by adjusting voltage, frequency, and electromagnetic force. That is, the electromagnetic field control unit 13 controls the intensity or duration of an electromagnetic field.

The electromagnetic field control unit 13 operates the electromagnetic field application coil 11 in such a manner that from prior to pouring the molten metal into the second sleeve 22, the second sleeve 22 is exposed to an electromagnetic field of the intensity so that solidification layers and/or dendrites are not formed in the molten metal at an early stage. Also, the electromagnetic field control unit 13 controls the electromagnetic field application coil 11 in such a manner that the electromagnetic field application to the second sleeve 22 is stopped when the molten metal reaches near its liquidus temperature, i.e., when crystalline nuclei are formed in the molten metal.

In this way, the electromagnetic field application of the electromagnetic field application coil 11 is controlled by the electromagnetic field control unit 13. As described above, the application of an electromagnetic field may be sustained until the prepared semi-solid metal slurry is pressed. However, in view of energy efficiency, an electromagnetic field may be applied until the slurry is manufactured, i.e., until the solid fraction of the slurry is 0.001 to 0.7. Preferably, the application of an electromagnetic field may be carried out until the solid fraction of the slurry is 0.001 to 0.4, and more preferably 0.001 to 0.1. The time required for accomplishing these solid fraction levels can be determined experimentally by comparing the measured temperature of the molten metal and the temperature in the phase diagram of a corresponding metal material.

Turning to FIG. 1, the first sleeve 21 and the second sleeve 22 have opposed ends that are hinge-connected. The second sleeve 22 can move within a predetermined angle, preferably, less than 90 degrees, with respect to the first sleeve 21. The second sleeve 22 may be installed in the space 12 defined by the stirring unit 1 in such a way to be concentric with the electromagnetic field application coil 11.

The first and second sleeves 21 and 22 may be made of a metal material or an insulating material such as ceramic. Preferably, the first and second sleeves 21 and 22 may be made of a material having a melting point higher than the molten metal M. The first and second sleeves 21 and 22 may also be made of a non-magnetic material.

In particular, the second sleeve 22 may be made of a non-magnetic metal or an insulating material. Therefore, when an electromagnetic field is applied to the second sleeve 22, the second sleeve 22 does not cause induction heating and heat generation, which is helpful in cooling the molten metal contained in the second sleeve 22. Also, the cooling of the molten metal may be initiated simultaneously with pouring the molten metal into the second sleeve 22. When the second sleeve 22 is made of a non-magnetic metal material, it is preferable to use a material having a melting point higher than the temperature of the molten metal.

When the temperature of the second sleeve 22 is raised to that of the molten metal, there is a risk that the second sleeve 22 may be molten. For this reason, the temperature of the second sleeve 22 cannot be raised to that of the molten metal. In this regard, when an electromagnetic field is applied to the second sleeve immediately after pouring the molten metal, dendrites may be instantly formed at inner wall portions of the second sleeve 22 contacting with the molten metal due to a high temperature difference between the second sleeve 22 and the molten metal.

Meanwhile, the first sleeve 21 is in a cylindrical form parallel to the ground and the second sleeve 22 can move at a predetermined angle with respect to an end of the first sleeve 21 connected to the second sleeve 22. In such a structure, as will be described later, the second sleeve 22 corresponds to the slurry manufacturing area T for retaining the molten metal and manufacturing the slurry by electromagnetic stirring, and the first sleeve 21 corresponds to an area for press-forming the manufactured slurry.

That is, the second sleeve 22 acts as a slurry manufacturing vessel for manufacturing the semi-solid slurry using the molten metal and the first sleeve 21 acts as a forming die for press-forming the manufactured slurry. Here, both ends of each of the first and second sleeves 21 and 22 are not necessarily open. There are no particular limitations on the structures of the first and second sleeves 21 and 22 provided that the first and second sleeves are connected to each other, and the semi-solid metal slurry S manufactured in the second sleeve 22 moves into the first sleeve 21 and then released from the first sleeve 21.

In detail, the first sleeve 21 is in a long, slender cylindrical form with both ends open and is fixedly installed in a horizontal axis direction. The first sleeve 21 has the same diameter as that of the second sleeve 22. A blocking member 20 is installed at an end of the first sleeve 21. A slurry outlet port 23 of a predetermined shape is defined by the blocking member 20. The semi-solid slurry S is released from the first sleeve 21 via the slurry outlet port 23. The slurry outlet port 23 is present at the end opposite to the end of the first sleeve 21 coupled with the second sleeve 22.

An extrusion device with an extrusion unit 6 is installed downstream of the slurry outlet port 23. The extrusion unit 6 is used as a forming unit to form an extrudate E, which is a product of a predetermined shape, using the slurry released from the slurry outlet port 23. The extrusion unit 6 is installed outside the slurry outlet port 23 of the first sleeve 21.

The extrusion unit 6 includes a transfer roller 61 for transferring the extruded slurry. A plurality of spray-type coolers 62 for cooling the slurry released from the slurry outlet port 23 of the first sleeve 21 are installed above a transfer surface 60 of the transfer roller 61. A cutter 63 is installed outside and above the slurry outlet port 23 of the first sleeve 21 to be moved in an upward and a downward direction to cut the semi-solid slurry S released from the slurry outlet port 23. The cutter 63 is installed so that the edge of the cutter 63 faces downward. When the slurry is released to a desired length from the slurry outlet port 23, the cutter cuts the released slurry by moving in a downward direction.

In the extrusion unit 6, the semi-solid metal slurry is transferred by the transfer roller 61, cooled by the coolers 62, and cut to a predetermined length by the cutter 63, to form the extrudate E in the form of a wire or a sheet.

Since the slurry released from the slurry outlet port 23 is transferred to the extrusion unit 6, the slurry outlet port 23 of the first sleeve 21 determines the shape of the slurry S to be released from the slurry outlet port 23. The shape of the slurry outlet port 23 may be determined by the shape of the extrudate E to be formed in the extrusion unit 6 installed downstream of the slurry outlet port 23. That is, as will be described later, since the slurry S is released from the slurry outlet port 23 and transferred to the extrusion unit 6, the shape of the slurry released is first determined by the slurry outlet port 23. In this regard, the shape of the slurry outlet port 23 varies depending on the shape of the extrudate to be formed in the extrusion unit 6. If the extrudate extruded from the slurry outlet port 23 is of a wire form, a circular outlet port may be used, while if the extrudate is of a sheet form, a rectangular outlet port may be used.

Meanwhile, a slurry inlet port 24 is present at the other end of the first sleeve 21 opposite to the slurry outlet port 23. The slurry outlet port 23 and the slurry inlet port 24 communicate concentrically with each other. The slurry inlet port 24 is formed to have a shape conforming to that of the slurry outlet port 26 of the second sleeve 22 so as to communicate concentrically with the slurry outlet port 26. Therefore, the slurry S manufactured in the second sleeve 22 is released from the slurry outlet port 23 via the slurry inlet port 24.

The first sleeve 21 may be formed in a shape gradually flared from the slurry inlet port 24 to the slurry outlet port 23. That is, the inner diameter of the first sleeve 21 may be gradually increased toward the releasing direction of the slurry, i.e., from the slurry inlet port 24 to the slurry outlet port 23. Therefore, the inner diameter of the first sleeve 21 may be equal to or larger than that of the second sleeve 22.

A first temperature control unit 41 may be further installed around the first sleeve 21, as shown in FIGS. 1 and 3 through 6. The first temperature control unit 41 adjusts the temperature of the semi-solid slurry S in the first sleeve 21 by adjusting the temperature of a predetermined area of the first sleeve 21. That is, the first temperature control unit 41 serves to prevent the semi-solid slurry S pressed in the first sleeve 21 from rapidly cooling. In this regard, the first temperature control unit 41 has a predetermined heat insulating function.

In detail, the first temperature control unit 41 includes a common water jacket 43 containing a spiral pipe 42. The water jacket 43 is concentrically installed around the first sleeve 21 to surround the outside of the first sleeve 21. By

appropriately adjusting the temperature of a medium which flows in the pipe 42, the temperature of the slurry in the first sleeve 21 can be adjusted.

The pipe 42 may also be buried in the first sleeve 21. Any temperature control units capable of adjusting the temperature of the slurry contained in the first sleeve 22 may be used. An electric heater (not shown) may also be used as the first temperature control unit 41.

Meanwhile, a first plunger 52 as a first pressing device is slidably inserted in the injection port 25 of the second sleeve 22. The first plunger 52 can move reciprocally like a piston in the first and second sleeves 21 and 22 while being connected to a separate cylinder unit (not shown), which is in turn connected to a controller (not shown). Here, a press face 54 which is a front end of the first plunger 52 may be a flat surface perpendicular to the moving direction of the first plunger 52.

When the slurry is manufactured in the second sleeve 22, the first plunger 52 is inserted into the injection port 25 of the second sleeve 22 to block the injection port 25 of the second sleeve 22. The first plunger 52 moves together with the second sleeve 22 in a state of being inserted into the injection port 25 of the second sleeve 22, thereby preventing the spill out of the slurry from the injection port 25 of the second sleeve 22. When the slurry outlet port 26 of the second sleeve 22 communicates with the slurry inlet port 24 of the first sleeve 21 by removal of the stopper 31, the first plunger 52 pushes the slurry in the second sleeve 22 toward the slurry outlet port 23 of the first sleeve 21. Therefore, the slurry is transferred to the transfer surface 60 of the transfer roller 61 of the extrusion unit 6 from the slurry outlet port 23.

In other words, the first plunger 52 is away from the injection port 25 of the second sleeve 22 while the second sleeve 22 is exposed to an electromagnetic field and the molten metal in the second sleeve 22 is cooled, i.e., while the semi-solid slurry is manufactured from the molten metal in the second sleeve 22, as shown in FIG. 1. After the slurry is manufactured in the second sleeve 22, the first plunger 52 is inserted into the injection port 25 and pushes the slurry in the second slurry 22. The first plunger 52 moves together with the second sleeve 22, and pushes the slurry toward the first sleeve 21.

A thermocouple (not shown) may be installed in each of the first sleeve 21 and the second sleeve 22 and connected to a controller for providing the temperature information of the molten metal and the slurry to the controller.

Meanwhile, a pouring unit 51 is used to pour the molten metal into the second sleeve 22. The pouring unit 51 may be a common ladle electrically connected to a controller (not shown). In addition, any pouring units such as a furnace, which melts a metal material, directly connected to the second sleeve 22, may be used provided that the molten metal can be poured into the second sleeve 22.

Hereinafter, operation of the rheoforming apparatus having the aforementioned structure according to the first embodiment of the present invention will be described.

Turning to FIG. 1, first, the second sleeve 22 moves at a predetermined angle, preferably 90 degrees with respect to the first sleeve 21 so that the injection port 25 of the second sleeve 22 faces upward. At the same time, the slurry outlet port 24 of the second sleeve 22 is sealed by the stopper 31 to allow the second sleeve 22 to act as a vessel for receiving the molten metal.

Next, the electromagnetic field control unit 13 operates the electromagnetic field application coil 11 of the stirring unit 1 in such a manner that the empty second sleeve 22 is exposed to an electromagnetic field of the intensity so that solidification layers or dendrites are not formed in the molten metal to be poured at an early stage.

At this time, the electromagnetic field application coil 11 may apply an electromagnetic field with an intensity of 500 Gauss at 250 V and 60 Hz, but is not limited thereto. It is understood that the intensity of an electromagnetic field may be appropriately adjusted according to process conditions.

In this state, the molten metal M that has molten in a separate furnace is poured via the pouring unit 51 such as a ladle into the second sleeve 22 under an electromagnetic field. Here, to promote formation of the molten metal poured in the second sleeve 22 into the semi-solid slurry S and to prevent spill out of the molten metal through a gap between the slurry outlet port 26 and the stopper 31 of the second sleeve 22, the solid fraction of the semi-solid slurry is relatively increased.

The furnace and the second sleeve 22 may also be directly connected to each other for directly pouring the molten metal into the second sleeve 22. As described above, the molten metal may have a temperature of 100℃ above its liquidus temperature. The second sleeve 22 may be connected to a separate gas supply

tube (not shown) for supplying an inert gas such as $N_2$ and Ar, thereby preventing the oxidation of the molten metal.

In this way, when the molten metal is poured into the second sleeve 22 under the electromagnetic stirring, fine crystalline particles are distributed throughout the second sleeve 22, without formation of solidification layers at an early stage. The crystalline particles rapidly grow, thereby preventing the formation of dendritic structures.

Application of an electromagnetic field by the electromagnetic field application coil 11 may be carried out simultaneously with the pouring of the molten metal into the second sleeve 22.

The application of an electromagnetic field may be sustained until the semi-solid slurry S is pressed by the first plunger 52, i.e., the solid fraction of the slurry is in a range of 0.001 to 0.7, preferably 0.001 to 0.4, and more preferably 0.001 to 0.1. The time required for accomplishing these solid fraction levels can be determined by previous experiments. The application of an electromagnetic field is carried out during so determined time.

After completion or in the middle of application of an electromagnetic field, the molten metal in the second sleeve 22 is cooled at a predetermined rate until the solid fraction of the molten metal is in a range of 0.1 to 0.7 to manufacture the semi-solid slurry.

In this case, a cooling rate may be adjusted to 0.2 to 5.0℃/sec, preferably 0.2 to 2.0℃/sec, by the second temperature control unit 44 installed around the second sleeve 22, as described above. Of course, the cooling may be spontaneously carried out. The time ($t_2$) required for reaching the solid fraction of 0.1 to 0.7 can be determined by previous experiments.

The semi-solid metal slurry made from the molten metal in the second sleeve 22 has the solid fraction to an extent so that the semi-solid metal slurry is not spilled out from the slurry outlet port 26 of the second sleeve 22 and the slurry inlet port 24 of the first sleeve 21 while the slurry outlet port 26 is coupled with the slurry inlet port 24.

After the semi-solid metal slurry is manufactured in the second sleeve 22, the first plunger 52 is inserted into the injection port 25 of the second sleeve 22. In this state, when the second sleeve 22 moves at an angle of 90 degrees, the slurry outlet port 26 of the second sleeve 22 is coupled with the slurry inlet port 24 of the first

sleeve 21 via the stopper 31, as shown in FIG. 3. At this time, the first plunger 52 moves together with the second sleeve 22.

Then, the stopper 31, which is a sealing member, is removed so that the slurry outlet port 26 communicates with the slurry inlet port 24.

In this state, the first plunger 52 pushes the slurry S in the second sleeve 22 toward the slurry outlet port 23 of the first sleeve 21 to force the slurry S into the extrusion unit 6 from the slurry outlet port 23, as shown in FIG. 4.

During the pressing in the first sleeve 21, the temperature of the slurry can be preserved to a predetermined level by the first temperature control unit 41.

As shown in FIG. 5, the slurry released from the slurry outlet port 23 is transferred by the transfer roller 61 while being rapidly cooled by the coolers 62 of the extrusion unit 6 and cut by the cutter 63, which is positioned above the slurry outlet port 23, to form the extrudate E of a predetermined shape.

The extrudate E is transferred to a collection unit (not shown) by the transfer roller 61. On the other hand, a biscuit B left in the first sleeve 21 is removed by a separate ejection unit (not shown) after returning the first plunger 52 to an original position and moving back the second sleeve 22 at an angle of 90 degrees to open the slurry inlet port 24 of the first sleeve 21, as shown in FIG. 6.

After the biscuit B is removed, the aforementioned process is repeated by pouring a molten metal into the second sleeve 22, as shown in FIG. 1. Therefore, the fine and uniform extrudate E can be obtained.

As described above, according to the first embodiment of the present invention, spherical particles can be obtained by remarkably increasing the density of nuclei at the inner wall of the second sleeve with stirring at a temperature above the liquidus temperature of the molten metal within a short time. Therefore, the semi-solid slurry of fine, uniform, spherical particles can be manufactured in the second sleeve 22. As a result, the operation duration can be reduced, thereby minimizing energy loss. Even though the second sleeve 22 has an unsymmetrical shape instead of a cylindrical shape, the semi-solid slurry of fine, uniform, spherical particles can be manufactured.

Also, since the semi-solid metal slurry in the second sleeve 22 is transferred to the extrusion unit 6 via the first sleeve 21, the high quality extrudate E can be obtained at a low pressure. Therefore, power loss can be prevented and the operation duration can be reduced. At the same time, the reduction of durability of

constitutional elements due to pressing of the slurry can be prevented and energy loss can be reduced. Therefore, the high quality extrudate E with fine and uniform structures can be continuously manufactured within a short time.

Also, due to improved energy efficiency, a manufacture cost can be reduced and the mechanical properties of the extrudate can be enhanced. In addition, since the extrudate E can be simply manufactured within a short time, the entire manufacturing process can be simplified and productivity can be enhanced.

Meanwhile, a portion of the slurry exposed to air may be oxidized. According to the present invention, since the second sleeve 22 for manufacturing the slurry is vertically positioned, an upper portion of the slurry is oxidized. The oxidized portion of the slurry is left on the biscuit B without being transferred to the extrusion unit 6, as shown in FIGS. 5 and 6. Since the biscuit B is removed, the oxidized portion is also removed together with the biscuit B. Therefore, the high quality extrudate E can be obtained.

In the first embodiment, the molten metal is injected through the injection port 25 which is an end of the second sleeve 22, and the semi-solid slurry S in the second sleeve 22 is pressed by the first plunger 52 inserted into the injection port 25. However, according to a second embodiment of the present invention as shown in FIG. 8, a separate pouring hole 28 is branched from the second sleeve 22 and the molten metal is poured into the second sleeve 22 from the pouring hole 28. In this structure, the first plunger 52 may be permanently inserted in the injection port 25 of the second sleeve 22. Such a structure of the second sleeve 22 and the first plunger 52 may be applied in all embodiments as will be described later.

According to a third embodiment of the present invention as shown in FIGS. 9 through 14, the aforementioned rheoforming apparatus may be used as a press-forming apparatus provided with a press-forming unit 7 which is installed outside the slurry outlet port 23 of the first sleeve 21, instead of the extrusion unit 6 that forms the extrudate E from the slurry released from the slurry outlet port 23. The press-forming unit 7 includes press dies 71 and 72 and forms a product with a shape conforming to the shape defined by the press dies 71 and 72 using the slurry released from the slurry outlet port 23 of the first sleeve 21.

In the rheoforming apparatus according to the third embodiment of the present invention, first, the slurry is manufactured from the molten metal M poured into the second sleeve 22, as shown in FIG. 9. The slurry outlet port 26 of the

second sleeve 22 is then coupled with the slurry inlet port 24 of the first sleeve 21 by moving the second sleeve 22, as shown in FIG. 10. Then, the slurry outlet port 26 of the second sleeve 22 is opened by removal of the sealing member 3 so that the slurry outlet port 26 communicates with the slurry inlet port 24 of the first sleeve 21.

In this state, the first plunger 52 pushes the slurry in the second sleeve 22 toward the slurry outlet port 23 of the first sleeve 21. At this time, the temperature of the slurry can be preserved by the first temperature control unit 41 installed around the first sleeve 21. As shown in FIGS. 12 and 13, the slurry released from the slurry outlet port 23 of the first sleeve 21 is formed into a product P with a predetermined shape by pressing using the press dies 71 and 72 and cut by the cutter 63, which is positioned above the slurry outlet port 23.

The biscuit B left in the first sleeve 21 is removed by a separate ejection unit after returning the first plunger 52 to an original position and moving back the second sleeve 22 at a predetermined angle to open the slurry inlet port 24 of the first sleeve 21, as shown in FIG. 14. After the biscuit B is removed, the aforementioned process is repeated by pouring a molten metal into the second sleeve 22, as shown in FIG. 9. Therefore, the product P with a fine and uniform particle structure can be obtained.

Like in the first embodiment, according to this embodiment of the present invention, because the molten metal is subjected to press-forming in the form of a slurry, the high quality product P can be manufactured at a low pressure. As a result, the loss of an electric energy and the operation duration can be reduced.

Even though an upper portion of the manufactured slurry may be oxidized, the oxidized portion is removed together with the biscuit B without being formed. Therefore, a high quality product can be obtained.

According to a fourth embodiment of the present invention as shown in FIGS. 15 and 17, a rheoforming apparatus of the present invention may be used as a die-casting apparatus having a forming die 8. That is, the rheoforming apparatus according to the fourth embodiment of the present invention includes the forming die 8, which is installed outside the slurry outlet port 23. The forming die 8 includes a moving die 81 and a fixing die 82. When the moving die 81 and the fixing die 82 meet with each other, a forming cavity 83 of a predetermined shape is defined by the moving die 81 and the fixing die 82. The fixing die 82 is formed with a funnel 84 for directing the slurry into the forming cavity 83. The funnel 84 communicates with the

slurry outlet port 23 of the first sleeve 21. The semi-solid metal slurry S released from the slurry outlet port 23 is directed into the forming cavity 83.

The moving die 81 and the fixing die 82 are respectively supported by support plates 85a and 85b which are attached to the entire equipment (not shown). When the forming is completed, the moving die 81 is separated from the fixing die 82 and a die cast formed in the forming cavity 83 is removed.

In the rheoforming apparatus according to the fourth embodiment of the present invention, first, the slurry is manufactured from the molten metal M poured into the second sleeve 22, as shown in FIG. 15. Then, the second sleeve 22 is coupled with the first sleeve 21, as shown in FIG. 16, and the slurry outlet port 26 of the second sleeve 22 is opened by removal of the sealing member 3, as shown in FIG. 17.

In this state, the first plunger 52 pushes the slurry in the second sleeve 22 toward the slurry outlet port 23 of the first sleeve 21. Then, the slurry released from the slurry outlet port 23 of the first sleeve 21 is directed into the forming die 8. At this time, the slurry S is inserted into the forming cavity 83 via the funnel 84 of the forming die 8 and rapidly cooled, to form the die cast corresponding to the shape of the forming cavity 83, as shown in FIG. 17. When the forming is completed, the moving die 81 is separated from the fixing die 82. Therefore, the die cast can be removed from the forming cavity 83.

Like in the first embodiment, according to this embodiment of the present invention, because the molten metal is subjected to die-casting in the form of a slurry, the high quality die cast can be manufactured at a low pressure. As a result, the loss of an electric energy and the operation duration can be reduced. Also, since the slurry with a low temperature is inserted in the forming die 8 under a low pressure, the reduction of the lifespan of the forming die 8 is prevented. In addition, since an upper portion of the manufactured slurry may be oxidized but is not inserted into the forming die 83, a high quality product can be obtained.

Meanwhile, the aforementioned rheoforming apparatus may be modified according to a fifth embodiment of the present invention as shown in FIGS. 18 and 19. According to the fifth embodiment, the first sleeve 21 is installed in a vertical direction. The second sleeve 22 is installed on the first sleeve 21 so that the slurry inlet port 24 of the first sleeve 21 communicates concentrically with the slurry outlet port 26 of the second sleeve 22. Therefore, the first sleeve 21 is connected to the

lower end of the second sleeve 22. The second sleeve 22 is fixedly installed on support frames 14 and 15.

Here, the inner peripheral surface of each of the second sleeve 22 and the first sleeve 21 may be formed in a shape flared in a downward direction so that the semi-solid metal slurry S manufactured in the second sleeve 22 can be dropped by its own gravity. Also, a forming unit such as the forming die 8 is installed outside the slurry outlet port 23 of the first sleeve 21. FIG. 18 shows only the forming die 8, but is not limited thereto. The above-described extrusion unit or press-forming unit may also be provided.

In the rheoforming apparatus according to the fifth embodiment of the present invention, the first sleeve 21 and the second sleeve 22 are fixedly coupled with each other. The sealing member 3 as described above is interposed between the first sleeve 21 and the second sleeve 22. The first sleeve 21 and the second sleeve 22 may also be integrally formed. In this case, the sealing member 3 may be installed in an inner side of an integrally formed sleeve.

First, the slurry is manufactured using the molten metal M poured into the second sleeve 22 from the injection port 25, as shown in FIG. 18. Then, the slurry outlet port 26 of the second sleeve 22 is opened by removal of the sealing member 3 so that the semi-solid metal slurry S in the second sleeve 22 can be dropped in the first sleeve 21 by its own gravity. At this time, the slurry S manufactured in the second sleeve 22 has a solid fraction to an extent so that the slurry S can be dropped by its own gravity. Then, the first plunger 52 is inserted into the injection port 25 of the second sleeve 22 and forces the slurry in the first sleeve 21 toward the forming die 8.

The slurry S is inserted into the forming cavity 83 via the funnel 84 of the forming die 8 and rapidly cooled, to form the die cast corresponding to the shape of the forming cavity 83. At this time, a separate cooler (not shown) may rapidly cool the slurry inserted in the forming cavity 83. When the forming is completed, the moving die 81 is separated from the fixing die 82. Therefore, the die cast can be removed from the forming cavity 83.

Like in the fourth embodiment, according to this embodiment of the present invention, because the molten metal is subjected to die-casting in the form of a slurry, the high quality die cast can be manufactured at a low pressure. As a result, the loss of an electric energy and the operation duration can be reduced. Also, since

the slurry with low temperature is inserted in the forming die 8 under a low pressure, the reduction of the lifespan of the forming die 8 is prevented. In addition, since the slurry S manufactured in the second slurry 22 can be dropped in the first sleeve 21 by its own gravity, the moving of the slurry from the second sleeve 22 to the first sleeve 21 can be easily performed.

In the above structure, the second sleeve 22 may have a shape flared in a downward direction, as described above. The first sleeve 21 may also be formed in a shape flared in a downward direction. That is, the first and second sleeves 21 and 22 may be formed in a flared shape so that when the slurry manufactured is dropped in the direction of the forming die 8 by its own gravity or pressed by the first plunger 52, the cross-sections of the first sleeve 21 and the second sleeve 22 are increased in the direction of the forming die 8 to promote the moving of the slurry.

According to a sixth embodiment of the present invention as shown in FIGS. 20 and 21, an end of the second sleeve 22 may be connected to the body of the first sleeve 21. That is, the second sleeve 22 may be branched from the first sleeve 21. In this embodiment, the first sleeve 21 is installed so that its axis direction is parallel to the ground. The second sleeve 22 is connected to the body of the first sleeve 21 to be positioned above the first sleeve 21. A second plunger 53 for pressing is slidably inserted in an opening 30 of the first sleeve 21. Here, a press face 55 which is a front face of the second plunger 53 is a flat surface perpendicular to the moving direction of the second plunger 53.

A forming unit such as the forming die 8 is installed outside the slurry outlet port 23 of the first sleeve 21. FIG. 20 shows only the forming die 8, but is not limited thereto. The above-described extrusion unit or press-forming unit may also be provided.

The second sleeve 22 is inclined at an angle of about 45 degrees with respect to the first sleeve 21 so that the injection port 25 of the second sleeve 22 is positioned away from the first sleeve 21. The slurry outlet port 26 of the second sleeve 22 is connected to about intermediate portion of the body of the first sleeve 21. The stopper 31 as the sealing member 3 is removably installed near the slurry outlet port 26 of the second sleeve 22 to open or close the slurry outlet port 26. The stirring unit 1 is installed around the second sleeve 22, as described above.

The second sleeve 22 may be formed with the separate pouring hole 28 for pouring the molten metal. The pouring hole 28 is positioned at a higher position

than the stirring unit 1 and is protruded in an upward direction from the body of the second sleeve 22. The pouring hole 28 communicates with the second sleeve 22. The molten metal M is poured in the slurry manufacturing area T from the pouring hole 28 under an electromagnetic field applied by the stirring unit 1.

Meanwhile, the second sleeve 22 may be formed in a shape flared in the direction of the first sleeve 21. By doing so, the slurry manufactured in the second sleeve 22 can be easily dropped in the first sleeve 21 by its own gravity or by the first plunger 52.

As shown in FIG. 20, the molten metal M is poured in the second sleeve 22 from the pouring hole 28 in a state wherein the stopper 31 is closed, and is formed into the slurry by an electromagnetic field applied by the stirring unit. Then, the slurry outlet port 26 of the second sleeve 22 is opened by upward removal of the stopper 31 so that the slurry advances toward the first sleeve 21. At this time, when the first plunger 52 pushes the slurry toward the first sleeve 21, the moving of the slurry toward the first sleeve 21 can be promoted.

When the slurry is inserted in the first sleeve 21, the second plunger 53 forces the slurry toward the slurry outlet port 23 so that the slurry is inserted into the forming die 8, as shown in FIG. 21. The slurry is inserted into the forming cavity 83 via the funnel 84 and rapidly cooled to form the die cast having a shape corresponding to that of the forming cavity 83. At this time, a separate cooler (not shown) may rapidly cool the slurry inserted in the forming cavity 83. When the forming is completed, the moving die 81 is separated from the fixing die 82. Therefore, the die cast can be removed from the forming cavity 83.

Like in the fourth embodiment, according to this embodiment of the present invention, because the molten metal is subjected to die-casting in the form of a slurry, the high quality die cast can be manufactured at a low pressure. As a result, the loss of an electric energy and the operation duration can be reduced. Also, since the slurry with low temperature is inserted in the forming die 8 under a low pressure, the reduction of the lifespan of the forming die 8 is prevented.

According to a seventh embodiment of the present invention as shown in FIG. 22, the first sleeve 21 may be installed vertically with respect to the ground and the second sleeve 22 may be branched from the first sleeve 21. Therefore, the slurry manufactured can easily move in the direction of the forming die 8 by its own gravity, thereby promoting a manufacture process. For this, both the second sleeve 22 and

the first sleeve 21 may be formed in a shape gradually flared from their own inlet port.

As described above, in the sixth and seventh embodiments, since an upper portion of the slurry may be oxidized but is not inserted in the forming die 8, a high quality product can be obtained.

Meanwhile, in the sixth and seventh embodiments, the press face 54 which is the front face of the first plunger 52 may be inclined at an angle of about 45 degrees with respect to the moving direction of the first plunger 52 so that when the first plunger 52 advances toward the first sleeve 21, the press face 54 matches with the inner peripheral surface of the first sleeve 21.

In this case, the press face 54 of the first plunger 52 is formed in the same surface as the inner peripheral surface of the first sleeve 21 so that when the first plunger 52 pushes the slurry in the second sleeve 22, the entire slurry can be inserted into the first sleeve 21. That is, the press face 54 of the first plunger 52 is formed so that the slurry inlet port 24 of the first sleeve 21 is closed along the inner peripheral surface of the first sleeve 21 by the first plunger 52. Therefore, the slope of the press face 54 of the first plunger 52 is the same as the inclined angle of the second sleeve 22 with respect to the first sleeve 21.

The press face 54 which is the front face of the first plunger 52 may also be a flat surface perpendicular to the moving direction of the first plunger 52, according to an eight embodiment of the present invention as shown in FIG. 23.

The same acting effects as in the seventh embodiment can be achieved even when the forming die 8 is positioned at the upper end of the first sleeve 21 installed perpendicularly to the ground and the second plunger 53 is slidably inserted into the lower end of the first sleeve 21, according to a ninth embodiment of the present invention as shown in FIG. 24.

As described above, a rheoforming apparatus according to the present invention can be widely used for rheoforming various kinds of metals or alloys, for example, aluminum, magnesium, zinc, copper, iron, or an alloy thereof.

That is, in view of solidification theory, the temperature of a molten metal to be inserted in a sleeve can be discussed with respect to the specific heat of a metal or alloy material that make the molten metal.

The specific heat of aluminum is about 0.25 kcal/g. The specific heat of other metals except aluminum, for example, magnesium (about 0.18 kcal/g), zinc

(about 0.1 kcal/g), copper (about 0.1 kcal/g), and iron (about 0.1 kcal/g) is smaller than that of aluminum. In this regard, other metals except aluminum require a smaller thermal energy than aluminum. Therefore, even when molten metals made from these metals are inserted in a sleeve at a temperature of 100℃ above their liquidus temperature, latent heat is not generated. As a result, crystalline nuclei may grow in these molten metals by discharge of only the specific heat of the molten metals. Therefore, the above-described advantages can also be obtained from molten metals made from other metals or alloys except aluminum.

Theoretically, when the difference between a temperature ($T_l$) at which liquid phase is changed to solid phase and a temperature ($T_s$) at which solid phase is changed to liquid phase, i.e., $T_l$-$T_s$ = $\triangle T$, is zero (0), crystalline nuclei can be formed in molten metals made from any metals or alloys by setting the temperature of the molten metals within a temperature of $T_l$ to $T_s$.

Meanwhile, pure aluminum commonly used in the foundry industry contains about 1% of impurity. Also, pure magnesium, pure zinc, pure copper, and pure iron commonly used in the foundry industry also contain about 1% of impurity.

Therefore, when a magnetic field by electromagnetic field application is created in molten metals made from magnesium, zinc, copper, iron, and an alloy thereof in which $\triangle T$ is not "0" and the specific heat is smaller than aluminum, these metals and alloys can also provide the same results as in aluminum and an alloy thereof.

As apparent from the above descriptions, a rheoforming apparatus according to the present invention provides the following advantages.

First, products having a uniform, fine, and spherical particle structure can be manufactured.

Second, more nuclei can be formed at an inner wall of a sleeve within a short time through electromagnetic stirring at a temperature above the liquidus temperature of molten metals to thereby obtain spherical particles.

Third, manufactured products have improved mechanical properties.

Fourth, the duration of electromagnetic stirring is greatly shortened, thereby conserving a stirring energy.

Fifth, the simplified overall process and the reduced forming duration improve productivity.

Sixth, because products are formed from slurries, lower pressure forming is possible.

Seventh, because products are formed under a low pressure, durability of constitutional elements of the apparatus can be improved, and energy loss and manufacturing duration can be reduced.

Eighth, upper portions of slurries manufactured may be oxidized but the oxidized portions are removed together with biscuits without being formed. Therefore, high quality products can be obtained.

While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.